Charge distribution of cosmic rays above 1 TeV

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The first charge distribution of the primary cosmic rays with energies above 1 TeV in the interval $6 \leqslant Z \leqslant 15$ is reported. This distribution was measured by the Sokol-2 instrument aboard the Kosmos-1713 satellite. A method for significantly improving the accuracy of measurements of the charges of high-energy cosmic-ray particles in instruments of the Sokol type is described briefly.

We developed the Sokol instrument, which was used in measurements of cosmic rays with energies above 1 TeV on the Kosmos-1543 and Kosmos-1713 satellites, primarily to study the proton component. In designing the instrument we accordingly focused on measuring the charges of protons and helium nuclei. At $Z = 1$–2 one can expect distortions of the measured charges of the primary particles by particles of the return flux coming from the ionization calorimeter. In the Sokol instrument, which is described in Refs. 1 and 2, the effect of this return current on the charge detector was suppressed by using Cerenkov charge detectors, which made use of the directionality of Cerenkov radiation (DZ-1 detectors), and by carefully selecting the FÉU-49 photomultiplier for a uniform sensitivity over the entire area of the photocathode (required for a good separation of the particles with $Z = 1$ and $Z = 2$).

To measure the charges of nuclei with $Z \geqslant 5$, we used Cerenkov detectors with a thin radiator (a material equivalent to Plexiglas, 1 cm thick), in which the Cerenkov radiation scattered by the white walls of the detector housing was detected. These detectors (DZ-2) were accordingly sensitive to the return current. Furthermore, the working area of these detectors was significant, and the optical reflection coefficient of the white walls was about 0.85. Both of these factors made the amplitude of the light flash detected quite sensitive to the point at which the particle passed through detector DZ-2. This sensitivity was ultimately expressed in a large error in the charge measurements ($\sigma \simeq 1$ charge unit).

Such errors in the charge measurements by DZ-2, however, did not interfere with the primary function of this detector: to determine the flux of all nuclei with $Z > 5$. This information was required in order to check the validity of the measurements of the flux of protons and helium nuclei.

Figures 1a and 1b show the results of the measurements of the particle charge distribution carried out on the Kosmos-1713 satellite with the Sokol-2 instrument. It can be seen from Fig. 1a that in the measurements by the DZ-1 detector the particles with charges $Z = 1$ and $Z = 2$ are separated well. This distribution is essentially independent of the magnitude of the signal in DZ-2; i.e., it is insensitive to the return current of particles. Figure 1b shows the distribution of particles with respect to the charge measured by the DZ-2 detector.[4] Here we see a small peak at $Z = 6$, a slightly

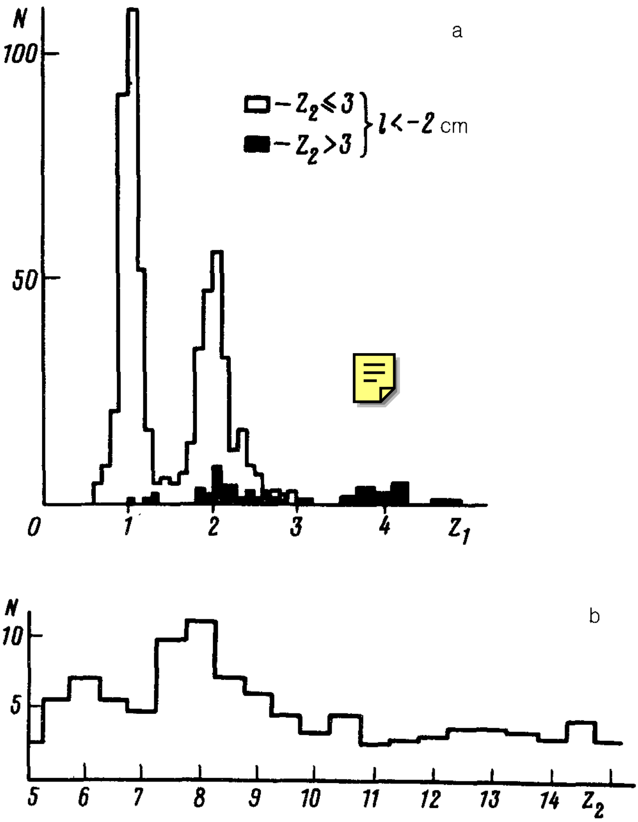

FIG. 1.

more obvious peak at $Z = 8$, and a peak at $Z = 26$ (see Ref. 4). In other words, at best this distribution lets us separate particles by groups.

In order to obtain information about the charge distribution of the particles, we need to improve the accuracy of the charge measurements. This can be done by making use of measurements of the charge of each particle by two detectors: DZ-1 (Z_1) and DZ-2 (Z_2). In this case we assign the particle a charge $Z = (Z_1 + Z_2)/2$. If, however, we take all particles, without any restrictions, we cannot improve the accuracy; we instead degrade it, for the following reasons. Detector DZ-1 has a radiator made of a material equivalent to Plexiglass with a thickness of 5 cm. In a thick radiator, about 20% of the nuclei will undergo interactions. The measured charge will differ greatly from the actual charge, and Z_2 will differ greatly from Z_1. Such events must of course be eliminated. About 7% of the particles will enter the radiator of DZ-1 through its lateral surface and traverse a short distance in this radiator. In this case again we would expect a large difference between Z_1 and Z_2. These cases must also be eliminated.

We accordingly introduced two additional requirements. We required that the particles pass no closer than 2 cm from the edge of the radiator of DZ-1. (The distance from the edge of the radiator of DZ-1 to the axis of the shower continued out of the ionization calorimeter was determined within 1 cm.) This requirement reduced the statistical base by a factor of 1.8. It eliminated the passage of particles through the lateral surface of the radiator of DZ-1. Furthermore, the particles which satisfy this condition passed through a region of the photocathode of the FÉU-49 in which the sensitivity was more nearly uniform than at the periphery. The effect was to improve the accuracy of the measurements of Z_1.

To reduce the fraction of the particles which underwent an interaction in the radiator of DZ-1, we imposed the condition $|(Z_1 - Z_2)/\sqrt{2}| \leqslant 1$. Let us explain the meaning of this condition.

If we plot Z_1, along the X axis, and Z_2 along the Y axis, each measurement of the charge by two detectors will be shown in the XY plane by a point with the coordinates Z_1 and Z_2. The results of the charge measurements by the two detectors will constitute a set of points which lie along the straight line $Z_1 = Z_2$. If a point has the coordinates Z_1 and Z_2, its distance from the line $Z_1 = Z_2$ will be d, where $d = (Z_1 - Z_2)/\sqrt{2}$. Since the error in the determination of the charge by detector DZ-2 is $\sigma(Z_2) \simeq 1$, we required $|d| \leqslant 1$. This requirement reduced the statistical base by a factor of 1.45. Together, the two requirements reduced the statistical base by a factor of 2.6.

From the overall statistical base we selected particles which satisfied these additional requirements, and for them we determined the charge $Z = (Z_1 + Z_2)/2$. Figure 2 shows the distribution with respect to Z. We have limited this distribution to $Z = 15$ because the highest charge which could be measured in some of the counters of DZ-1 was 16.

The dashed line in Fig. 2 is a Gaussian distribution with $\sigma = 0.4$ for $6 \leqslant Z \leqslant 8$, with $\sigma = 0.5$ for $9 \leqslant Z \leqslant 12$, and with $\sigma = 0.5$ for $13 \leqslant Z \leqslant 15$. This distribution was calculated under the assumption that at particle energies $\gtrsim 1$ TeV the charge distribution of the nuclei is the same as at tens of GeV (Ref. 3).

The solid line in Fig. 2 shows the expected distribution. In Fig. 2 we clearly see

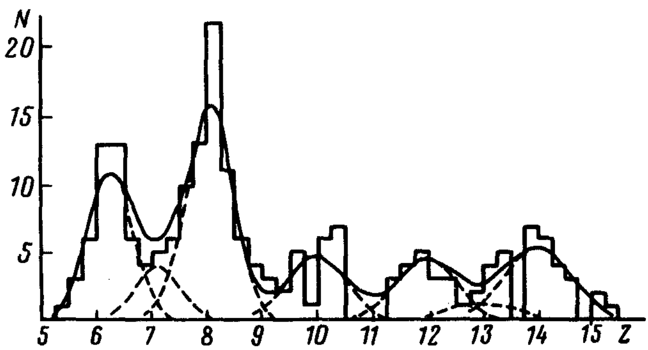

FIG. 2.

peaks at even charges and minima at odd charges in the distribution over the entire charge interval $6 \leqslant Z \leqslant 15$. A measure of the agreement of the expected distribution with the experimental distribution (the histogram) is $\chi^2 = 49$ with $\nu = 41$.

In conclusion we should point out that in the use of two types of charge detectors in the Sokol-2 instrument a high accuracy in the determination of the coordinates of the primary particle at the level of the charge detectors plays an important role in improving the accuracy of the measurements of the particle charges.

[1]N. L. Grigorov, Pis'ma Zh. Eksp. Teor. Fiz. **49**, 71 (1989) [JETP Lett. **49**, 83 (1989)].

[2]S. N. Vernov, I. P. Kumpan, L. G. Michenko *et al.*, in: 17th International Cosmic Ray Conference, Paris, Vol. 8, 1981, p. 49.

[3]M. Garcia-Munoz and J. A. Simpson, in: 16th International Cosmic Ray Conference, Kyoto, Vol. 1, 1979, p. 270.

[4]N. L. Grigorov, I. P. Ivanenko, I. D. Rapoport *et al.*, Vestn. Mosk. Univ. Fiz., No. 5, 44–50 (1988).

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